28 May 2010, 2:00 pm - 3:30 pm

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Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

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ABSTRACT

This paper describes 3-D finite element dynamic analysis of retaining wall structures with consideration of the soil-structure interaction. Purpose of this study is to reduce damages due to earthquake in such structures. For this reason, finite element program ANSYS has been used. The analysis data is based on 1995 Kobe earthquake report and the results have been verified with some retaining walls were damaged in that earthquake.

To take into account the non-linearity of soil-structure surface, surface to surface contact element is used. One of the most important problems in dynamic analysis is modeling of infinite media. If hinge or sliding support for soil boundary is used in finite element method, it would not define an acceptable boundary condition, because the transmitted earthquake waves reflect from the boundary and no energy would transmit out. For simulation of the unbounded nature of the soil medium, viscous (dashpot) boundary has been applied. Damping coefficient in both normal and perpendicular directions is given by Lysmer and Kuhlemeyer, and Drucker-Prager soil plasticity model is considered for non-linearity of soil.

To reach the appropriate reinforcement concrete behavior under the dynamic loads, material used for reinforcement concrete has also nonlinear behavior.

Results of classic method such as Coulomb and Rankine compared with the results of non-linear dynamic analysis.

INTRODUCTION

The recent large earthquakes, such as Northridge (1994), Kobe (1995) and Taiwan Chichi earthquake (1999), all have made serious damages to retaining wall structures.

Damages of these earthquakes indicate that collapses of retaining wall structures will result in tremendous losses of properties and lives. Therefore analysis and design of these structures against earthquake is vital.

This paper discusses about 3D nonlinear analysis of retaining wall structures under earthquake.

Dynamic finite element analysis method is one of the most popular methods for supervising the structure due to earthquake. In this regard finite element program ANSYS is used to consider the nonlinear bearing surface between structure and soil and to model nonlinear soil behavior related to Dracker-Prager and also nonlinear reinforced concrete behavior.

ANSYS has the ability to apply earthquake dynamic loads base on displacement time history. This paper describes the result of stress distribution in soil and reinforced concrete and compares the effect of various earthquakes and also soil properties on stress distribution.

THE MATERIAL MODEL

In order to material modeling behavior, the models which are exist in finite element program ANSYS are used.

Reinforced Concrete Modeling

3D ANSYS element solid65 that has ability of modeling reinforced concrete, used for retaining wall modeling. The modeled material with this element is capable to cracking in tension and crashing in compression. In addition, this material can undergo plastic deformation and creep (ANSYS, 2008).

This element has the ability to reinforce in 3 different directions and can consider plastic deformation and creep for reinforcement too (ANSYS, 2008).

Reinforcement concrete properties used in the model are as the following table.

Table 1. Concrete Characteristics

Compression Strength (kg/cm^2)	Mass Density (kN/m^3)	Poisson Ratio	Elasticity Modulus (N/m^2)
300	25	0.18	2.74E10

In this study Bangash curve used for modeling of concrete material in compression. And for modeling of reinfocement we used two linear elastic plastic behavior.

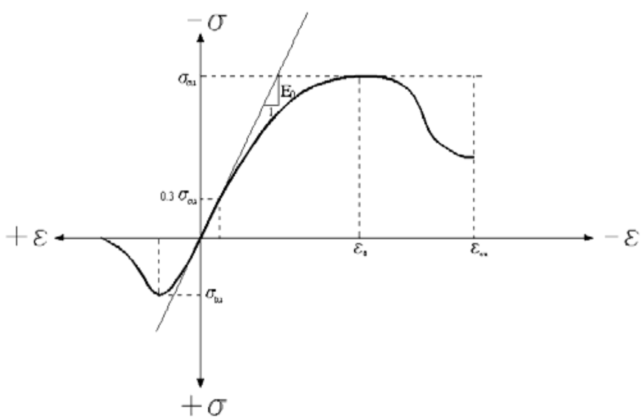

Fig. 1. Stress Strain Diagram of Concrete in Pressure.

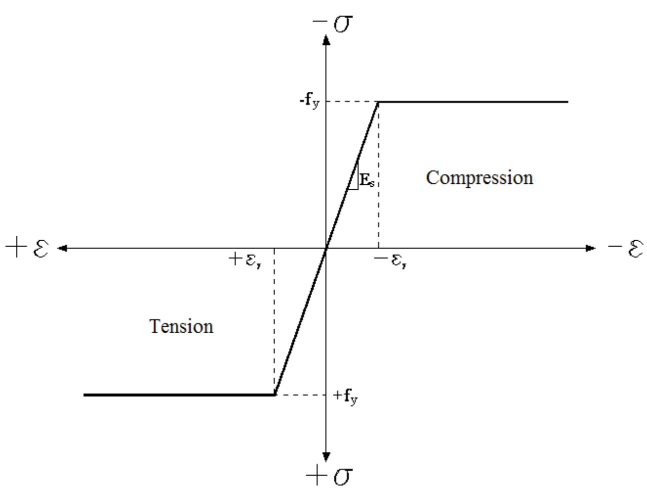

Fig. 2. Elastic Plastic Reinforcemnt Diagram.

<u>Soil Modeling</u>

In order to modeling of the soil behavior, Draker-Prager model has been used. Draker-Prager model is an estimation of Coulomb law with considering hydrostatic pressure. Draker-Prager yield function is as follow (Chen and Baladi, 1985):

$$F = 3\alpha\sigma_m + \sqrt{j_2'} - k' = 0$$

In which:

$$\alpha = (2\sin\varphi)/\left(\sqrt{3}(3-\sin\varphi)\right)$$

$$k' = (\sigma_c \sin\varphi)/\left(\sqrt{3}(3-\sin\varphi)\right)$$

where:

c and φ are cohesion and angle of internal friction of soil. σ_c, σ_m and j_2' are matrixes that represented in Chen and Baladi, 1985.

Soil is meshed with 3D solid45 ANSYS element that has 6 freedom degrees in each node (ANSYS, 2008). Elastic plastic soil prosperities that used in modeling are as the following table.

Table 2. Soil Characteristics

Cohesion	Internal Friction Angle (Degree)	Dilatancy Angle (Degree)	Mass Density (kN/m^3)	Poisson Ratio	Elasticity Modulus (N/m^2)
0	30	3	18	0.30	1.00E10

<u>Reinforcement Modeling</u>

Residual behaviors of concrete structure directly depend on residual behavior of reinforcement. To do the exact analysis, appropriate numerical model should be considered for reinforced concrete. Choosing the numerical model can affect on dynamic analysis which is used where dynamic forces like earthquake exist.

Residual erosion model, describes resistance properties can be calibrate with uniaxial test on reinforcement.

Staggered behavior model of stress-strain reinforcement curve can be dividing to two groups:

1- Immense models that are based on measuring relating between stress and strain.

2- Fine models that are based on displacement theory.

Fine models are concluded from simple theories but are such complicated that can not be used in nonlinear analysis for large structures. In other way immense models are simpler but they are unable to consider some residual behavior (Okamura and Maekawa, 1991).

THREE DIMENSIONAL RETAINING WALLS MODEL

Taking advantage of symmetry and anti symmetry only one fourth of the actual length of model was built in finite element software package ANSYS 11.

Eight node hexahedral elements with three transitional degrees of freedom at each node are used here.

The eight node element and finite element quarter model are used for retaining wall–soil system.

In order to modeling the concrete behavior of retaining wall, solid65 element and also for simulation of soil properties solid45 ANSYS element used.

Geometry of model based on actual retaining wall, was built, 65 years before Kobe earthquake in Shin-Nagata. This wall has 200m length and damaged in Kobe earthquake.

Dimensions of the wall and also the ANSYS finite element model are shown in following figures. On ANSYS modeling retaining wall modeled only between expansion joints.

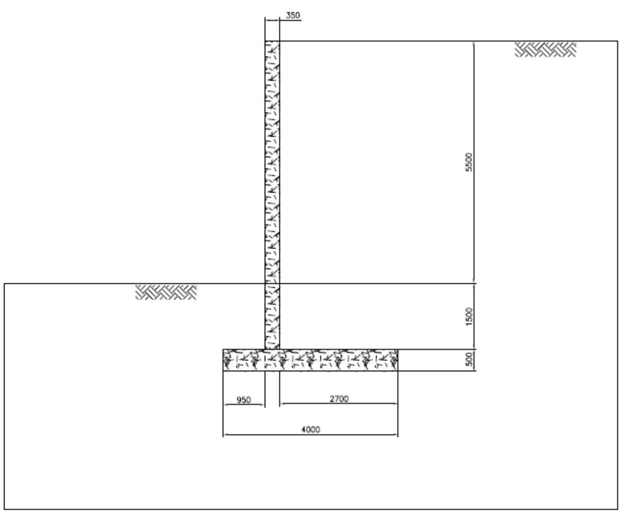

Fig. 3. Geometry of Retaining Wall.

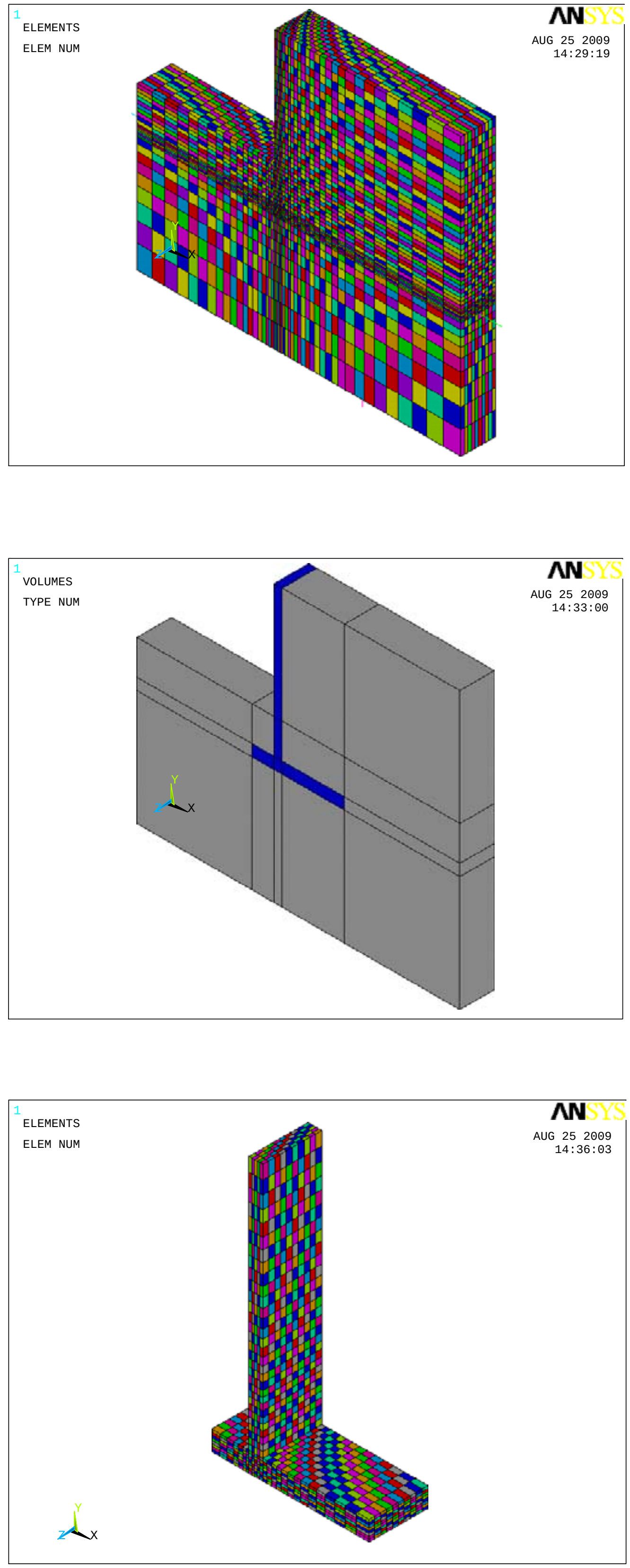

Fig. 4. ANSYS Finite Element Models.

BOUNDARY CONDITION

Infinite media modeling is one of the important problems in soil-structures dynamic analysis.

If hinge or sliding support for soil boundary has been used in finite element method, it would not define an acceptable boundary condition, because the transmitted earthquake wave reflects from the boundary and no energy would transmit out.

For simulation of the unbounded nature of the soil medium, two types of boundaries have been applied and the corresponding responses have been compared (Lysmer and Kuhlemeyer, 1969).

These boundaries are:

- Viscous (dashpot) boundary: viscous dampers are attached on the side face of the model. At a particular node where viscous dampers are attached, damping coefficients in normal and perpendicular directions are given by Lysmer and Kuhlemeyer (1969).

- Kelvin element (spring and dashpot) boundary: Kelvin elements are also used at the boundary. The stiffness and damping constant of the Kelvin element has been evaluated based on the solution developed by Novak and Mitwally (1988). Viscous and Kelvin element boundaries are shown in figure 5.

Fig. 5. Viscous and Kelvin Element Boundaries.

In this study we used Kelvin element as boundary condition.

ADEQUACY OF ANSYS FOR DYNAMIC ANALYSIS

ANSYS is a general purpose structural analysis program which has the capability to perform nonlinear time history analysis. This program uses displacement time history of earthquake as dynamic load.

In this study, for simulation correct earthquake condition, displacement time history of earthquake on down boundary of soil model is applied.

With ANSYS transient analysis result with displacement time histories could be reliable to study nonlinear response of structure under earthquake load.

The ANSYS program uses 3 methods to transient dynamic analysis; i.e. (1) full method, (2) reduced method and (3) superposition method (ANSYS, 2008).

Full method program create complete matrix and calculating response. This method is a powerful method compared with the other two methods since that full method has the capability to consider nonlinearity property such as plasticity, large deformation and etc. So in this study we used full method for dynamic transient analysis (ANSYS, 2008).

SEISMIC LOADING

Actual load of three great mentioned earthquakes, i.e. Kobe, Northridge and Chichi, with displacement time history are applied. These earthquakes are selected between other earthquakes. Displacement and acceleration time history of these earthquakes is shown in figures 6 and 7.

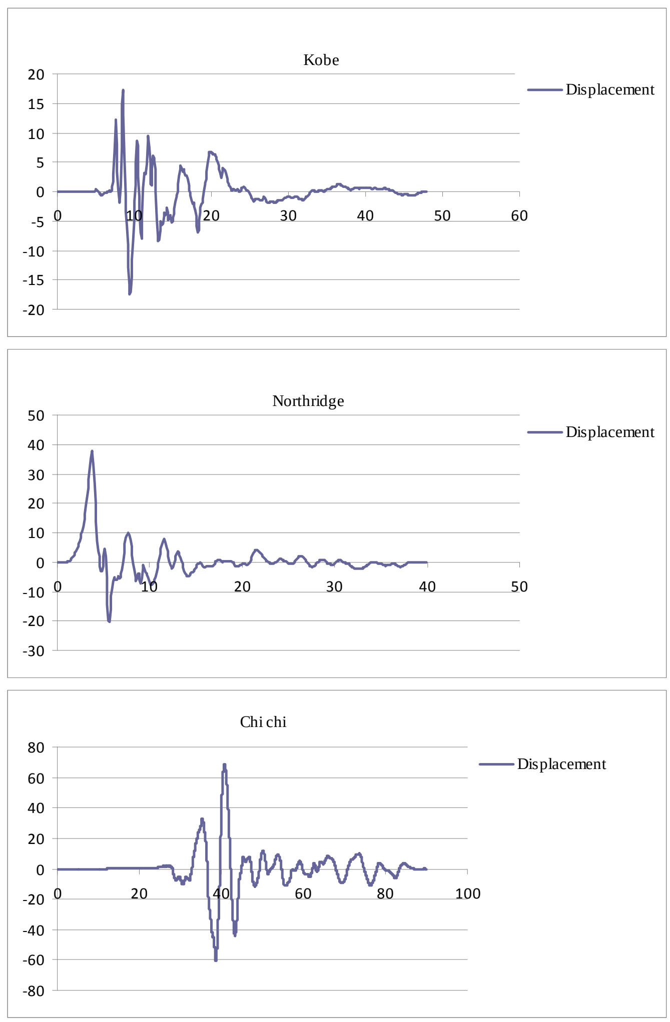

Fig. 6. Displacement of Kobe, Northridge and Chichi Earthquakes.

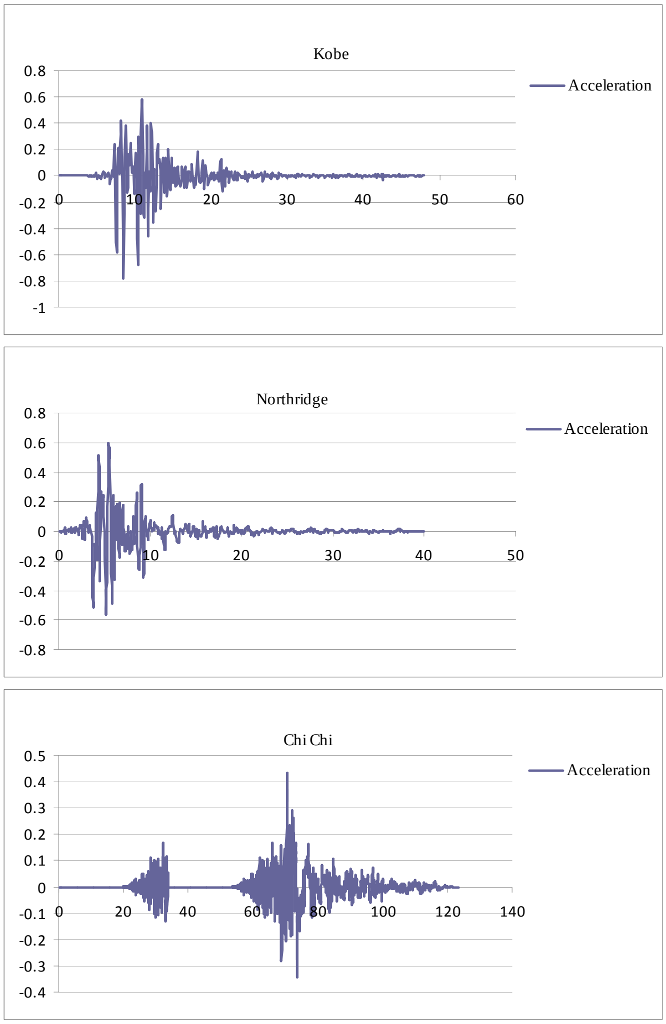

Fig. 7. Acceleration Time History of Kobe, Northridge and Chichi Earthquakes.

Table 3 also shows these earthquake properties.

Table 3. Earthquake Properties of Kobe, Northridge and Chichi.

	Kobe	**Northridge**	**Chichi**
PGA	0.789	0.690	0.439
PGV (cm/Sec)	80	90	120
PGD (cm)	17	39	71

VERIFYING MODELS

In order to verify this model, damage pattern of Shin-Nagata retaining wall that was damaged in Kobe earthquake, was compared with damage pattern of ours model.

After modeling Shin-Nagata concrete cantilever retaining wall, and applying Kobe earthquake as dynamic load on it, it was observed that crack pattern resulted from the analysis, completely compatible with Kobe earthquake report on Shin-Nagata wall.

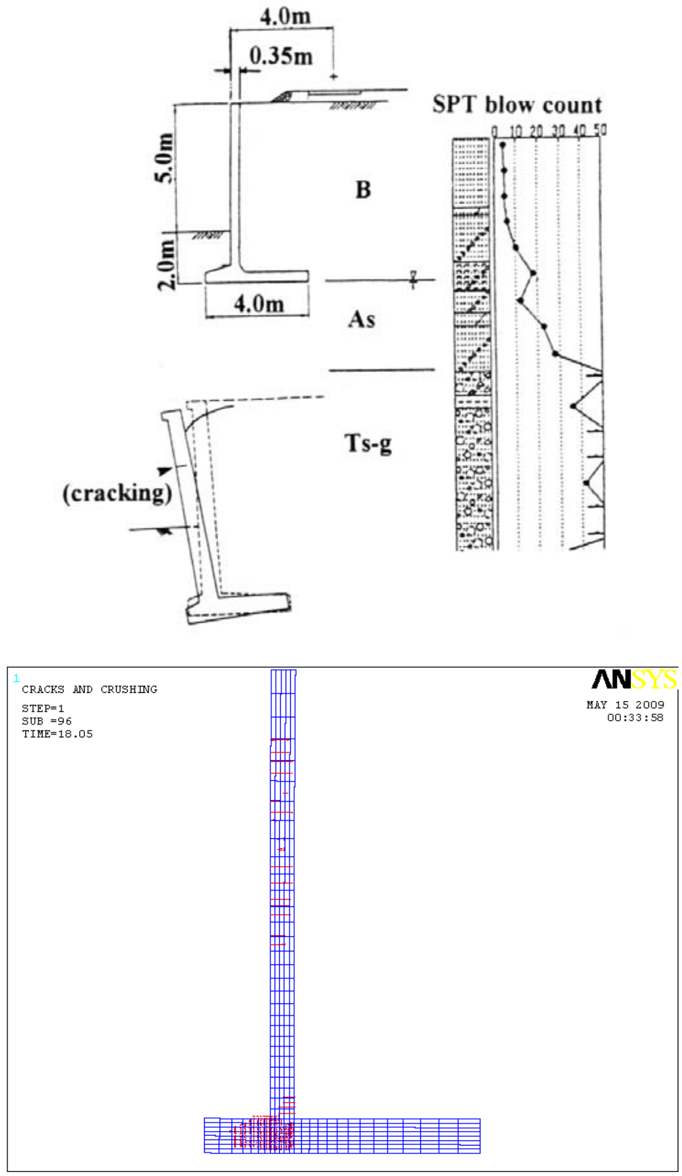

Fig. 8. Cracking Pattern of Retaining Wall.

RESULTS OF DYNAMIC ANALYSIS AT SOIL RUPTURE CONDITION

Active pressure and moments results of classical methods for cantilever walls and existence soil conditions are calculated based on Rankine and Coulomb methods with relevant formulas (Bowles, 1996 & Das, 2008). Final results of non-linear dynamic analysis are given in table 4.

Table 4. Compare of Dynamic Analysis Results with Classical Theories.

Method	K_a	K_p	P_a (KN/m)	P_p (KN/m)	M_a (KN.m/m)	M_p (KN.m/m)
Rankine	0.333	3	146.85	108	342.65	72
Coulomb	0.297	6.394	130.97	230.184	305.63	153.46
Coquot & Kerisel	0.297	5.643	130.97	203.148	305.63	135.43
Dynamic	-	Kobe	111.04	81.66	259.09	54.44
	-	North ridge	77.29	124.3	180.34	82.87
	-	Chichi	73.34	177.24	171.13	118.16

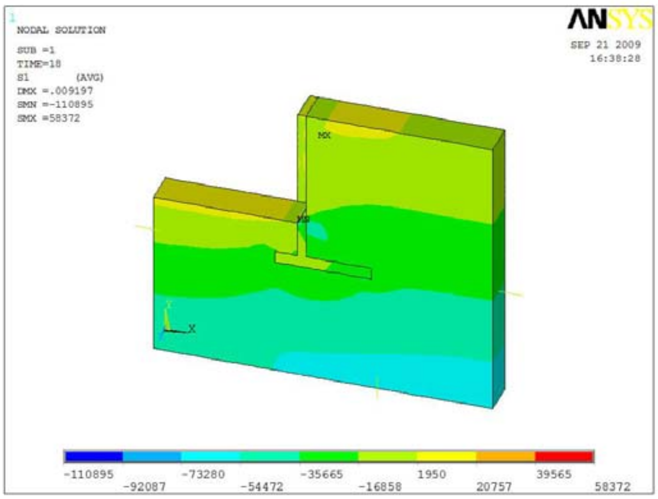

Fig. 9. Stress Distribution In Soil and Wall.

CONCLUSION

In general the maximum moment given from classic analysis, is over and safe and the results of dynamic analysis show this. The accuracy of stability height from analysis shows this fact that the stability height from some of these methods in compare with results of numerical analysis for cantilever walls is opposite of safety and in some others, like Rankine theory, is safe and for this reason high safety factor should be done on results.

Theory of passive Coulomb pressure distribution maximum up to 2 meters under excavation head (in front of the wall), for all of the wall is true and active Coulomb pressure distribution is compatible with results of numerical analysis back the wall with higher depth than passive pressure.

In addition in rigid cantilever retaining walls, pure pressure distribution has the same pattern with classic theories.

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